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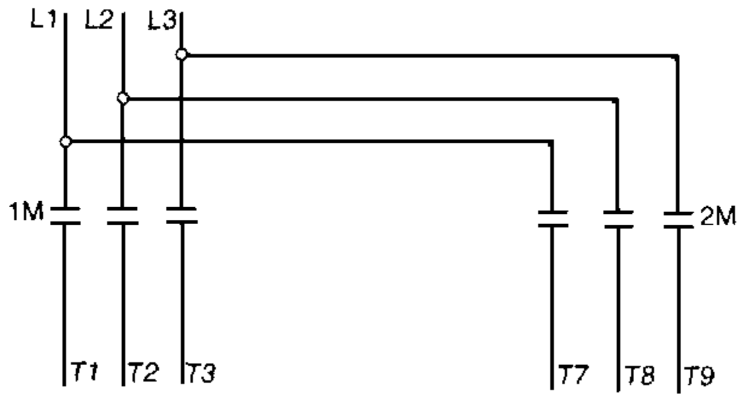


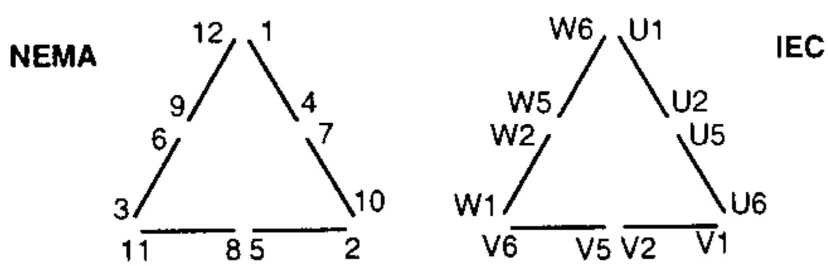
WYE OR DELTA CONNECTED

	T1	T2	T3	T7	T8	T9
MOTOR LEADS	1	2	3	7	8	9

NEMA NOMENCLATURE—9 LEADS
WYE CONNECTED (LOW VOLTAGE ONLY)

	T1	T2	T3	T7	T8	T9	Together
MOTOR LEADS	1	2	3	7	8	9	4&5&6

NEMA AND IEC NOMENCLATURE—12 LEADS
SINGLE VOLTAGE OR LOW VOLTAGE OF
DUAL-VOLTAGE MOTORS



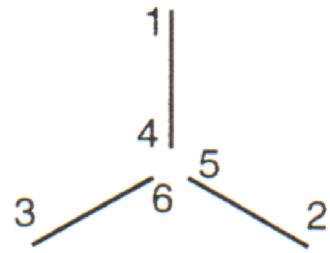
	T1	T2	T3	T7	T8	T9
NEMA	1,6	2,4	3,5	7,12	8,10	9,11
IEC	U1,W2	V1,U2	W1,V2	U5,W6	V5,U6	W5,V6

TERMINAL MARKINGS AND CONNECTIONS
THREE-PHASE MOTORS-SINGLE SPEED

NEMA NOMENCLATURE—6 LEADS

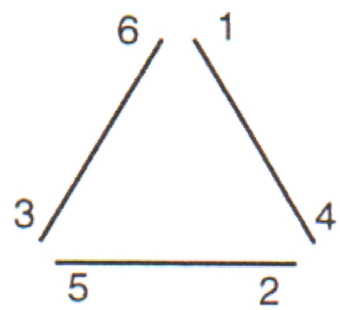
SINGLE VOLTAGE
EXTERNAL WYE CONNECTION

L1	L2	L3	JOIN
1	2	3	4&5&6

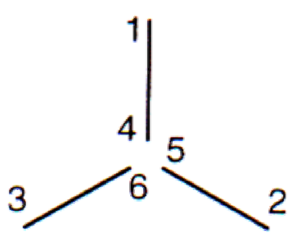


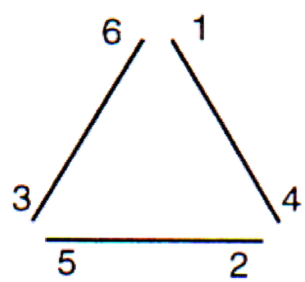
SINGLE VOLTAGE
EXTERNAL DELTA CONNECTION

L1	L2	L3
1,6	2,4	3,5



SINGLE AND DUAL VOLTAGE
WYE-DELTA CONNECTIONS





SINGLE VOLTAGE

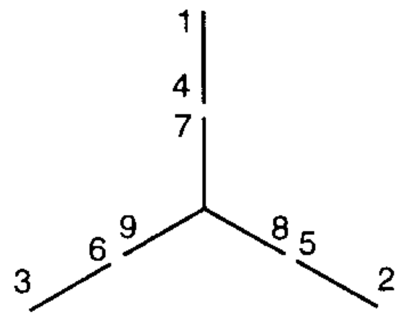
OPERATING MODE	CONNECTION	L1	L2	L3	JOIN
START	WYE	1	2	3	4&5&6
RUN	DELTA	1,6	2,4	3,5	---

DUAL VOLTAGE*

VOLTAGE	CONNECTION	L1	L2	L3	JOIN
HIGH	WYE	1	2	3	4&5&6
LOW	DELTA	1,6	2,4	3,5	---

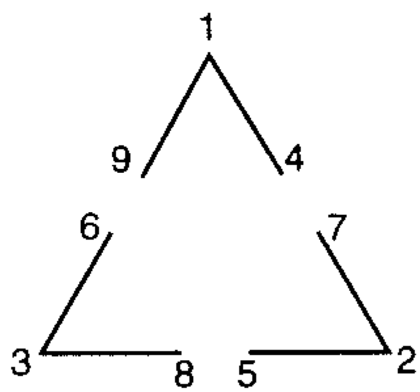
***Voltage Ratio: 1.732 to 1.**

NEMA NOMENCLATURE—9 LEADS



DUAL VOLTAGE
WYE-CONNECTED

VOLTAGE	L1	L2	L3	JOIN
HIGH	1	2	3	4&7, 5&8, 6&9
LOW	1,7	2,8	3,9	4&5&6

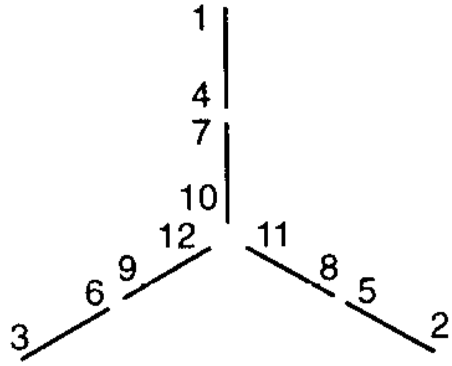


DUAL VOLTAGE
DELTA-CONNECTED

VOLTAGE	L1	L2	L3	JOIN
HIGH	1	2	3	4&7, 5&8, 6&9
LOW	1,6,7	2,4,8	3,5,9	---

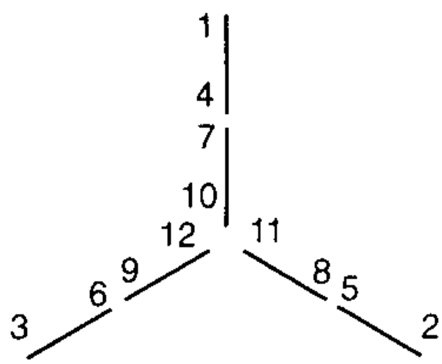
TERMINAL MARKINGS AND CONNECTIONS
THREE-PHASE MOTORS-SINGLE SPEED

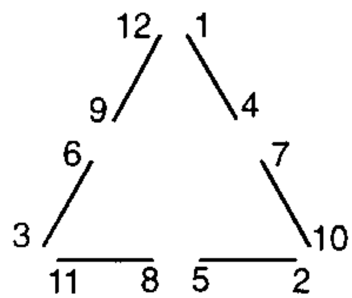
NEMA NOMENCLATURE--12 LEADS



DUAL VOLTAGE
EXTERNAL WYE CONNECTION

VOLTAGE	L1	L2	L3	JOIN
HIGH	1	2	3	4&7, 5&8, 6&9, 10&11&12
LOW	1,7	2,8	3,9	4&5&6, 10&11&12





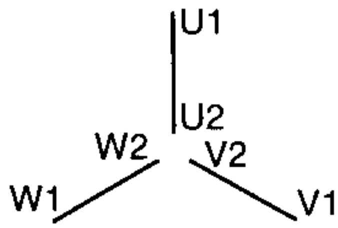
DUAL VOLTAGE
WYE-CONNECTED START
DELTA-CONNECTED RUN

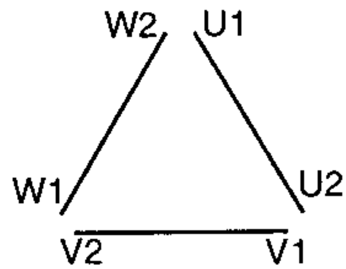
VOLTAGE	CONN.	L1	L2	L3	JOIN
HIGH	WYE	1	2	3	4&7, 5&8, 6&9, 10&11&12
	DELTA	1,12	2,10	3,11	4&7, 5&8, 6&9
LOW	WYE	1,7	2,8	3,9	4&5&6,10&11&12
	DELTA	1,6,7,12	2,4,8,10	3,5,9,11	---

THREE-PHASE MOTORS-SINGLE SPEED

IEC NOMENCLATURE—6 AND 12 LEADS

SINGLE AND DUAL VOLTAGE WYE-DELTA CONNECTIONS





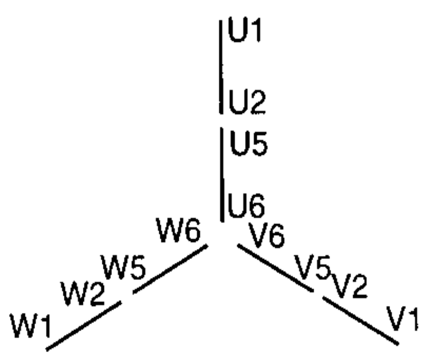
SINGLE VOLTAGE

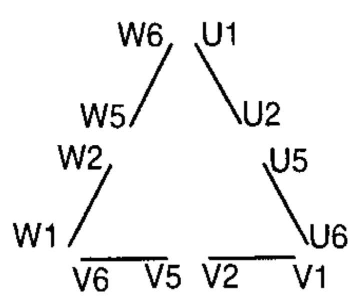
OPER. MODE	CONN.	L1	L2	L3	JOIN
START	WYE	U1	V1	W1	U2&V2&W2
RUN	DELTA	U1, W2	V1, U2	W1, V2	---

DUAL VOLTAGE*

VOLT	CONN.	L1	L2	L3	JOIN
HIGH	WYE	U1	V1	W1	U2&V2&W2
LOW	DELTA	U1, W2	V1, U2	W1, V2	

***Voltage Ratio: 1.732 to 1.**



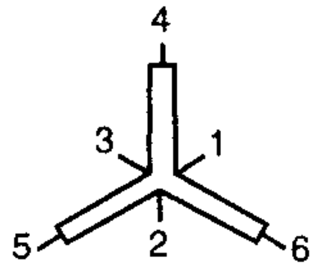


DUAL VOLTAGE WYE-CONNECTED START DELTA-CONNECTED RUN

VOLT	CONN.	L1	L2	L3	JOIN
HIGH	WYE	U1	V1	W1	U2&U5, V2&V5, W2&W5, U6&V6&W6
	DELTA	U1, W6	V1, U6	W1, V6	U2&U5, V2&V5, W2&W5
LOW	WYE	U1, U5	V1, V5	W1, W5	U2&V2&W2, U6&V6&W6
	DELTA	U1, U5, W2, W6	V1, V5, U2, U6	W1, W5, V2, V6	---

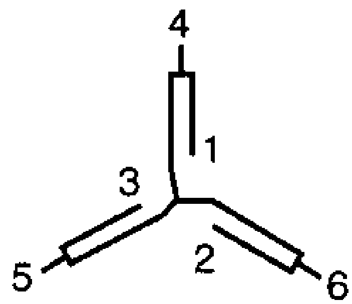
TERMINAL MARKINGS AND CONNECTIONS
THREE-PHASE MOTORS-TWO SPEED
SINGLE WINDING

NEMA NOMENCLATURE—6 LEADS



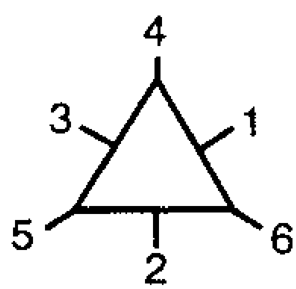
CONSTANT TORQUE CONNECTION
Low-speed horsepower is half
of high-speed horsepower.*

SPEED	L1	L2	L3		TYPICAL CONNECTION
HIGH	6	4	5	1&2&3 JOIN	2 WYE
LOW	1	2	3	4-5-6 OPEN	1 DELTA



VARIABLE TORQUE CONNECTION
Low-speed horsepower is one-fourth
of high-speed horsepower.*

SPEED	L1	L2	L3		TYPICAL CONNECTION
HIGH	6	4	5	1&2&3 JOIN	2 WYE
LOW	1	2	3	4-5-6 OPEN	1 WYE



CONSTANT HORSEPOWER CONNECTION
Horsepower is the same at both speeds.

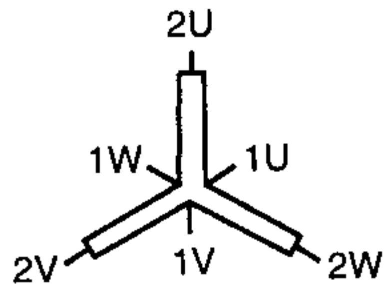
SPEED	L1	L2	L3		TYPICAL CONNECTION
HIGH	6	4	5	1-2-3 OPEN	2 DELTA
LOW	1	2	3	4&5&6 JOIN	1 WYE

***CAUTION: On European motors horsepower variance with speed may not be the same as shown above.**

TERMINAL MARKINGS AND CONNECTIONS
THREE-PHASE MOTORS-TWO SPEED,
SINGLE WINDING

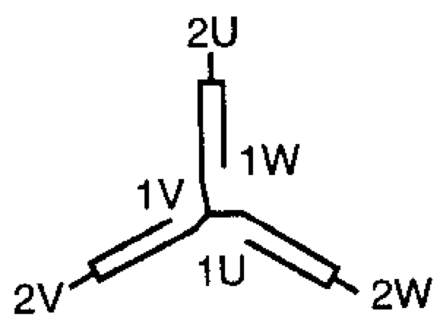
IEC NOMENCLATURE—6 LEADS

CONSTANT TORQUE CONNECTION



SPEED	L1	L2	L3		TYPICAL CONN.
HIGH	2W	2U	2V	1U&1V&1W JOIN	2 WYE
LOW	1U	1V	1W	2U-2V-2W OPEN	1 DELTA

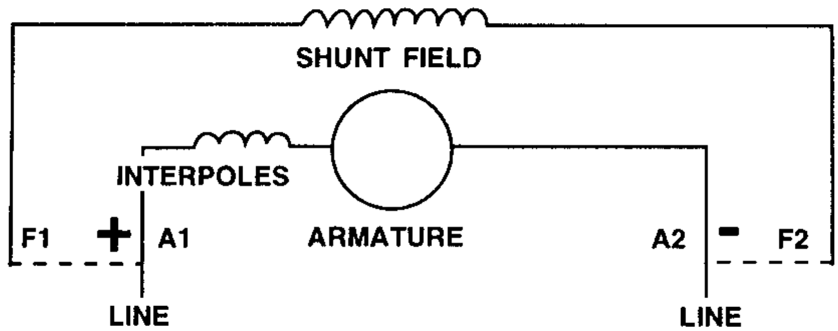
VARIABLE TORQUE CONNECTION



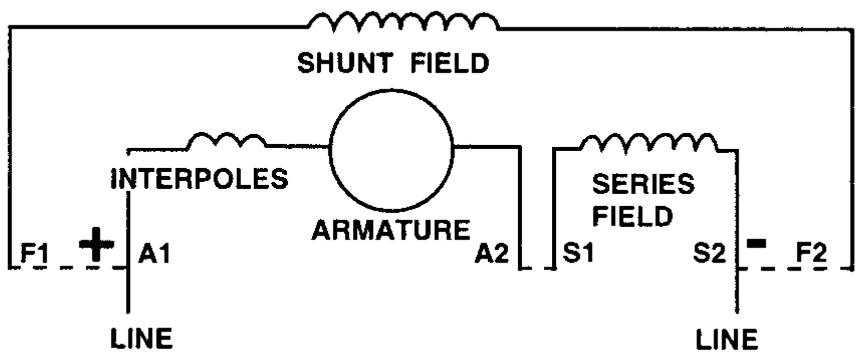
SPEED	L1	L2	L3		TYPICAL CONN.
HIGH	2W	2U	2V	1U&1V&1W JOIN	2 WYE
LOW	1U	1V	1W	2U-2V-2W OPEN	1 WYE

TERMINAL MARKINGS AND CONNECTIONS FOR NEMA DC MOTORS

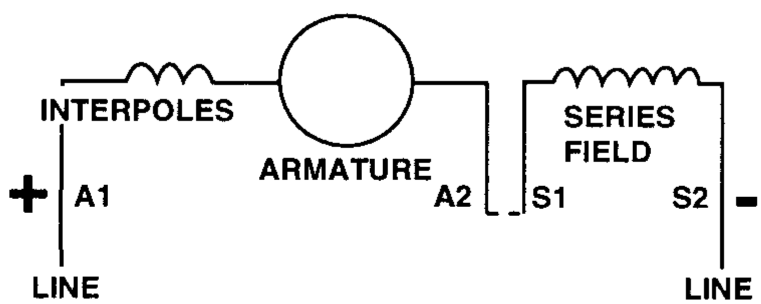
SHUNT MOTOR



COMPOUND MOTOR



SERIES MOTOR

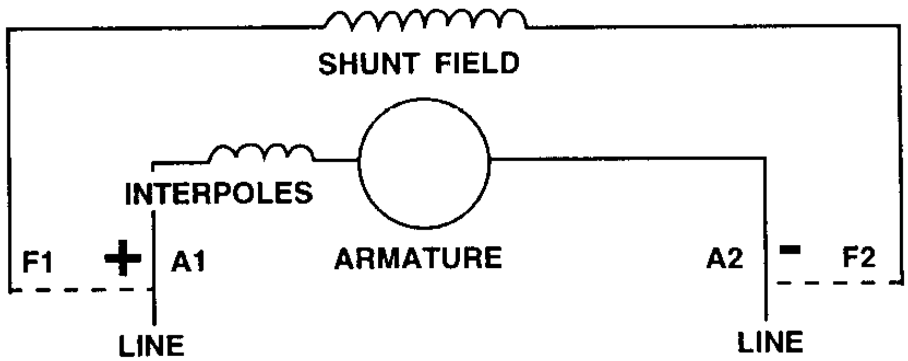


All connections are for counterclockwise rotation facing the end opposite the drive. For clockwise rotation, interchange A1 and A2.

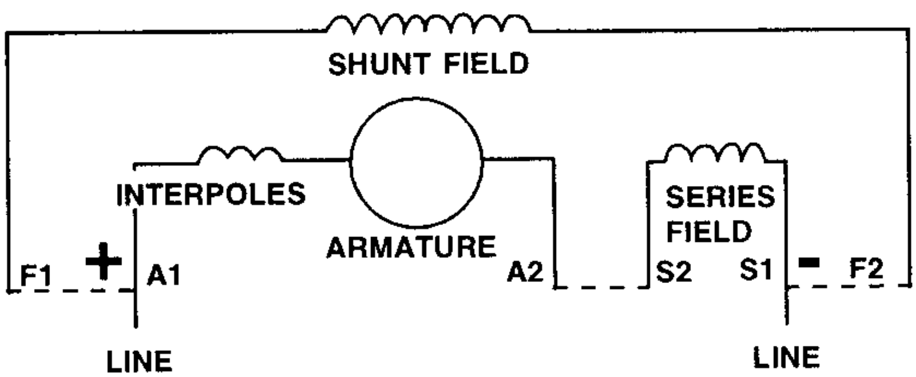
Some manufacturers connect the interpole winding on the A2 side of the armature.

When the shunt field is separately excited, the same polarities must be observed for a given rotation.

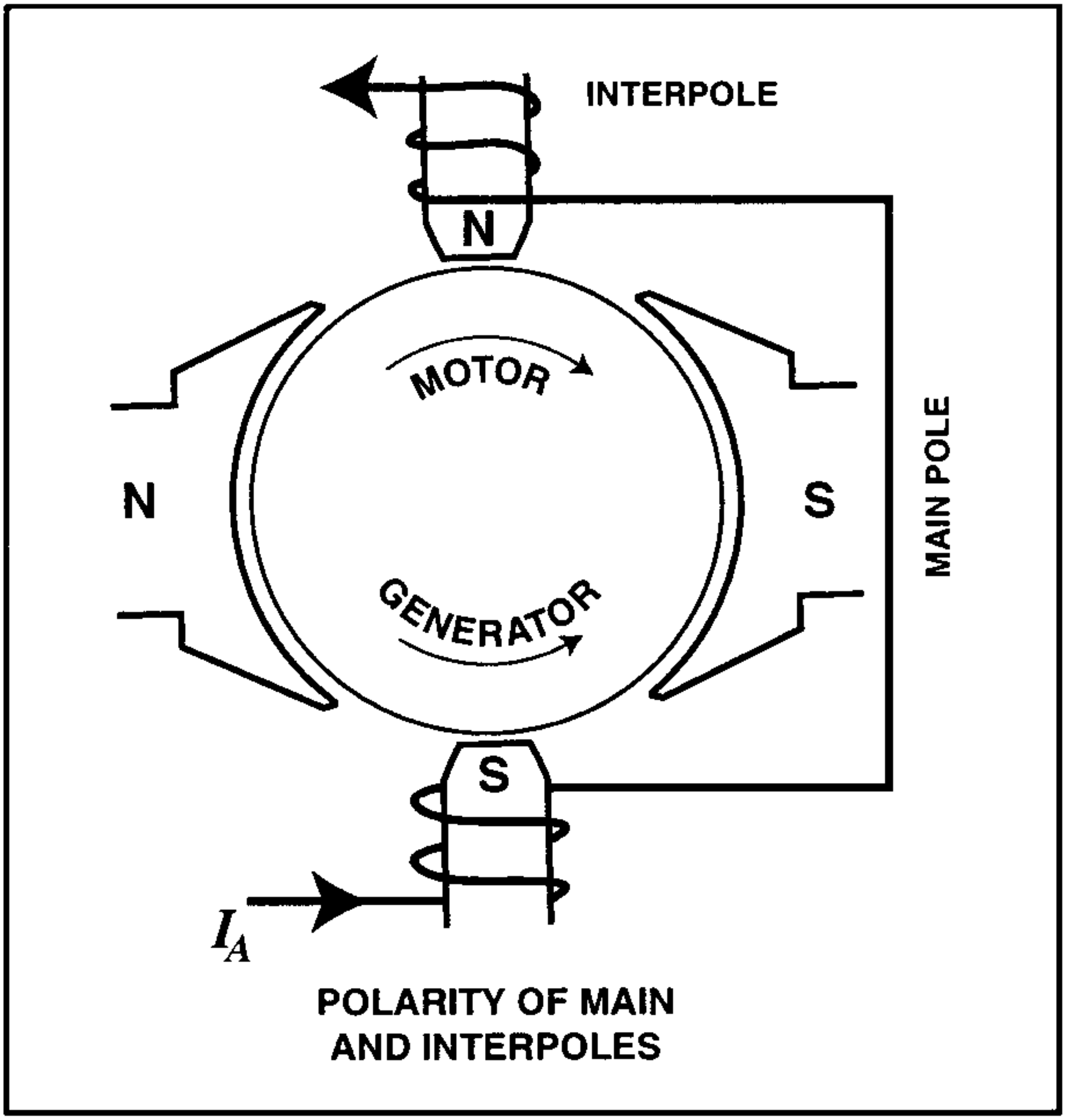
SHUNT GENERATOR



COMPOUND GENERATOR



All connections are for counterclockwise rotation facing the end opposite the drive. For clockwise rotation, interchange A1 and A2.
Some manufacturers connect the interpole winding on the A2 side of the armature.
For the above generators, the shunt field may be either self-excited or separately excited. When it is self-excited, connections should be made as shown. When the shunt field is separately excited, the same polarities must be observed for a given rotation.



The diagram above shows the polarity of interpoles with respect to the polarity of the main poles.
For a motor, the polarity of the interpole is the same as that of the main pole preceding it in the direction of rotation.
For a generator, the polarity of the interpole is the same as that of the main pole following it in the direction of rotation.

MAXIMUM LOCKED-ROTOR CURRENTS
THREE-PHASE SQUIRREL CAGE MOTORS
NEMA DESIGNS B, C & D

LOCKED-ROTOR CURRENT IN AMPERES

HP	RATED VOLTAGE					
	200V	230V	460V	575V	2300V	4000V
.5	23	20	10	8		
.75	29	25	12	10		
1	34	30	15	12		
1.5	46	40	20	16		
2	57	50	25	20		
3	74	64	32	26		
5	106	92	46	37		
7.5	146	127	63	51		
10	186	162	81	65		
15	267	232	116	93		
20	333	290	145	116		
25	420	365	182	146		
30	500	435	217	174		
40	667	580	290	232		
50	834	725	362	290		
60	1000	870	435	348	87	50
75	1250	1085	542	434	108	62
100	1665	1450	725	580	145	83
125	2085	1815	907	726	181	104
150	2500	2170	1085	868	217	125
200	3335	2900	1450	1160	290	167
250	4200	3650	1825	1460	365	210
300	5060	4400	2200	1760	440	253
350	5860	5100	2550	2040	510	293
400	6670	5800	2900	2320	580	333
450	7470	6500	3250	2600	650	374
500	8340	7250	3625	2900	725	417

The locked-rotor current of Design B, C and D constant-speed induction motors, when measured with rated voltage and frequency impressed and with rotor locked, shall not exceed the above values.
Reference: NEMA Standards MG 1-12.35.

MAXIMUM LOCKED-R0TOR CURRENTS
THREE-PHASE SQUIRREL CAGE MOTORS
NEMA DESIGN E

LOCKED-ROTOR CURRENT IN AMPERES

HP	RATED VOLTAGE					
	200V	230V	460V	575V	2300V	4000V
.5	23	20	10	8		
.75	29	25	13	10		
1	35	30	15	12		
1.5	46	40	20	16		
2	58	50	25	20		
3	84	73	37	29		
5	1140	122	61	49		
7.5	210	183	92	73		
10	259	225	113	90		
15	388	337	169	135		
20	516	449	225	180		
25	646	562	281	225		
30	775	674	337	270		
40	948	824	412	330		
50	1185	1030	515	412		
60	1421	1236	618	494	124	71
75	1777	1545	773	618	155	89
100	2154	1873	937	749	187	108
125	2692	2341	1171	936	234	135
150	3230	2809	1405	1124	281	162
200	4307	3745	1873	1498	375	215
250	5391	4688	2344	1875	469	270
300	6461	5618	2809	2247	562	323
350	7537	6554	3277	2622	655	377
400	8614	7490	3745	2996	749	431
450	9691	8427	4214	3371	843	485
500	10767	9363	4682	3745	936	538

The locked-rotor current of Design E constant-speed induction motors, when measured with rated voltage and frequency impressed and with rotor locked, shall not exceed the above values. Reference: NEMA Standards MG 1-12.35A.

NEMA CODE LETTERS FOR AC MOTORS

NEMA CODE LETTERS FOR LOCKED-ROTOR KVA

The letter designations for locked-rotor kVA per horsepower as measured at full voltage and rated frequency are as follows.

LETTER DESIGNATION	KVA PER HORSEPOWER*	LETTER DESIGNATION	KVA PER HORSEPOWER*
A	0.0– 3.15	K	8.0 – 9.0
B	3.15 – 3.55	L	9.0 – 10.0
C	3.55 – 4.0	M	10.0 – 11.2
D	4.0 – 4.5	N	11.2 – 12.5
E	4.5 – 5.0	P	12.5 – 14.0
F	5.0 – 5.6	R	14.0 – 16.0
G	5.6 – 6.3	S	16.0 – 18.0
H	6.3 – 7.1	T	18.0 – 20.0
J	7.1 – 8.0	U	20.0 – 22.4
		V	22.4 - & up

***Locked kVA per horsepower range includes the lower figure up to, but not including, the higher figure. For example, 3.14 is designated by letter A and 3.15 by letter B.**
Reference: NEMA Standards MG 1 – 10.37.2.

CODE LETTERS USUALLY APPLIED TO RATINGS OF MOTORS NORMALLY STARTED ON FULL VOLTAGE

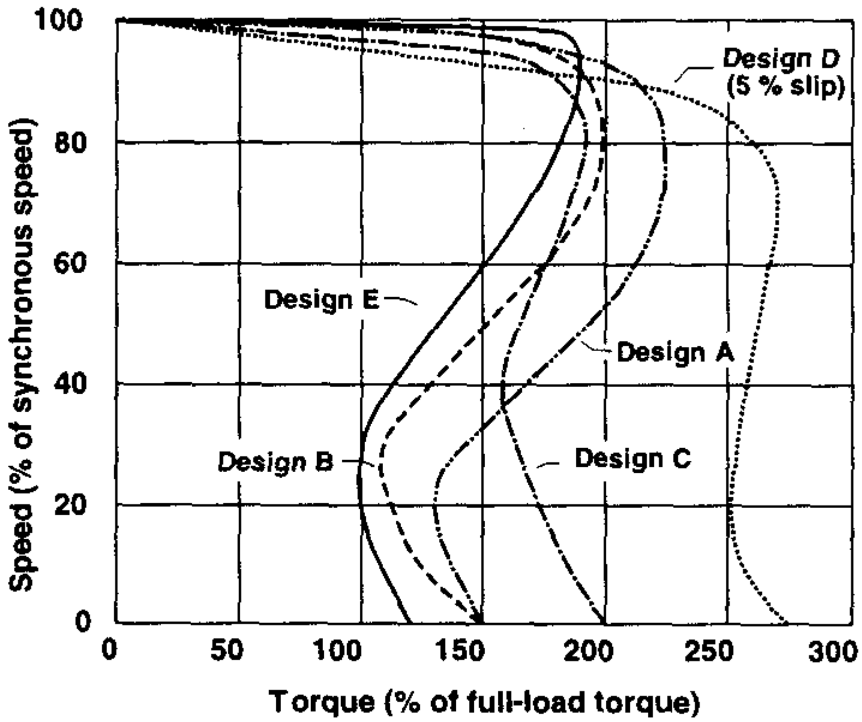
CODE LETTERS		F	G	H	J	K	L
Horse-power	3-phase	15 up	10 – 7½	5	3	2 – 1½	1
	1-phase	---	5	3	2 – 1½	1 - ¾	½

STARTING KVA PER HORSEPOWER FOR SINGLE-PHASE MOTORS

$$\text{Starting kVA per hp} = \frac{\text{Volts x Locked-Rotor Amps}}{\text{1000 X hp}}$$

1 for 1 Ø
1.732 for 3 Ø

GENERAL SPEED-TORQUE CHARACTERISTICS
THREE-PHASE INDUCTION MOTORS



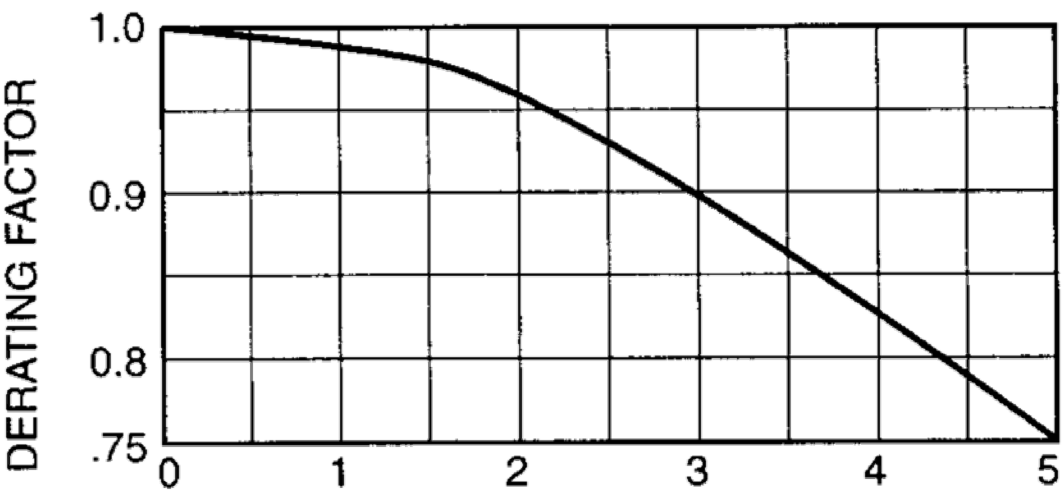
NEMA DESIGN	LOCKED ROTOR TORQUE	BREAKDOWN TORQUE	LOCKED ROTOR CURRENT	%SLIP	RELATIVE EFFICIENCY
B	70 – 275%*	175-300%*	600 – 700%	0.5 – 5%	Medium or High
	Applications: Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low.				
C	200 – 250%*	190 – 225%*	600 – 700%	1 – 5%	Medium
	Applications: Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required.				
D	275%	275%	600 – 700%	5 – 8% 8 – 13% 15 – 25%	Medium
	Applications: High peak loads with or without flywheels, such as punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping, and wire-drawing machines.				
E	75 – 190%*	160 – 200%*	800 – 1000%	0.5 – 3%	High
	Applications: Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low.				

Based on NEMA Standards MG 10, Table 2-1. NEMA Design A is a variation of Design B having higher locked-rotor current.
***Higher values are for motors having lower horsepower ratings.**

EFFECT OF VOLTAGE UNBALANCE
ON MOTOR PERFORMANCE

When the line voltages applies to a polyphase induction motor are not equal, unbalanced currents in the stator windings will result. A small percentage voltage unbalance will result in a much larger percentage current unbalance. Consequently, the temperature rise of the motor operating at a particular load and percentage voltage unbalance will be greater than for the motor operating under the same conditions with balanced voltages.
Should voltages be unbalanced, the rated horsepower of the motor should be multiplied by the factor shown in the graph below to reduce the possibility of damage to the motor. Operation of the motor at above a 5 percent voltage unbalance condition is not recommended.
Alternating current, polyphase motors normally are designed to operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1 percent. Performance will not necessarily be the same as when the motor is operating with a balanced voltage at the motor terminals.

MEDIUM MOTOR DERATING FACTOR DUE
TO UNBALANCED VOLTAGE



PERCENTAGE VOLTAGE UNBALANCE

Figure 2

$$\text{Percent Voltage Unbalance} = 100 \times \frac{\text{Max. Volt. Deviation from Avg. Volt.}}{\text{Average Volt.}}$$

Example: With voltages of 460, 467, and 450, the average is 459, the Maximum deviation from the average is 9, and the

$$\text{Percent Unbalance} = 100 \times \frac{9}{459} = 1.96 \text{ percent}$$

Reference: NEMA Standards MG 1 – 14.35.

STARTING CHARACTERISTICS OF SQUIRREL CAGE INDUCTION MOTORS

STARTING METHOD	VOLTAGE AT MOTOR	LINE CURRENT	MOTOR TORQUE
Full-Voltage Value	100	100	100
Autotransformer			
80% tap	80	64*	64
65% tap	65	42*	42
50% tap	50	25*	25
Primary Resistor Typical Rating	80	80	64
Primary Reactor			
80% tap	80	80	64
65% tap	65	65	42
50% tap	50	50	25
Series-Parallel	100	25	25
Wye-Delta	100	33	33
Part-Winding (½ - ½)			
2 to 12 Poles	100	70	50
14 and more Poles	100	50	50

Soft start is also available using solid-state controls.

Consult manufacturer for voltage, current and torque rating.

***Autotransformer magnetizing current not included. Magnetizing current is usually less than 25 percent of motor full-load current.**

ALLOWABLE STARTS AND STARTING INTERVALS
DESIGN A AND B MOTORS

HP	2 POLE			4 POLE			6 POLE		
	A	B	C	A	B	C	A	B	C
1	15	1.2	75	30	5.8	38	34	15	33
1.5	12.9	1.8	76	25.7	8.6	38	29.1	23	34
2	11.5	2.4	77	23	11	39	26.1	30	35
3	9.9	3.5	80	19.8	17	40	22.4	44	36
5	8.1	5.7	83	16.3	27	42	18.4	71	37
7.5	7.0	8.3	88	13.9	39	44	15.8	104	39
10	6.2	11	92	12.5	51	46	14.2	137	41
15	5.4	16	100	10.7	75	50	12.1	200	44
20	4.8	21	110	9.6	99	55	10.9	262	48
25	4.4	26	115	8.8	122	58	10.0	324	51
30	4.1	31	120	8.2	144	60	9.3	384	53
40	3.7	40	130	7.4	189	65	8.4	503	57
50	3.4	49	145	6.8	232	72	7.7	620	64
60	3.2	58	170	6.3	275	85	7.2	735	75
75	2.9	71	180	5.8	338	90	6.6	904	79
100	2.6	92	220	5.2	441	110	5.9	1181	97
125	2.4	113	275	4.8	542	140	5.4	1452	120
150	2.2	133	320	4.5	640	160	5.1	1719	140
200	2.0	172	600	4.0	831	300	4.5	2238	265
250	1.8	210	1000	3.7	1017	500	4.2	2744	440

Where: A = Maximum number of starts per hour.
B = Maximum product of starts per hour times load Wk^2.
C = Minimum rest or off time in seconds between starts.
Allowable starts per hour is the lesser of (1) A or (2) B divided by the load Wk^2, i.e.,

Starts per hour $\leq$ A or $\frac{B}{\text{Load } Wk^2}$, whichever is less.

Example: 25 hp, 4 pole, load Wk^2 = 50

From Table, A = 8.8, B = 122.

Starts per hour = $\frac{122}{50}$ = 2.44

Calculated value is less than A. Therefore allowable starts/hour = 2.44.

Note: Table is based on following conditions:

1. **Applied voltage and frequency in accordance with NEMA Standards MG 1-12.44.**
2. **During the accelerating period, the connected load torque is equal to or less than a torque which varies as the square of the speed and is equal to 100 percent of rated torque at rated speed.**
3. **External load Wk^2 equal to or less than the values listed in Column B.**

For other conditions, consult the manufacturer.
Reference: NEMA Standards MG 10, Table 2-3.

NEMA SIZE STARTERS
FORTHREE-PHASE MOTORS

NEMA SIZE	MAXIMUM HORSEPOWER—POLYPHASE MOTORS											
	FULL-VOLTAGE STARTING			AUTO-TRANSFORMER STARTING			PART-WINDING STARTING			WYE-DELTA STARTING		
	200V	230V	460V 575V	200V	230V	460V 575V	200V	230V	460V 575V	200V	230V	460V 575V
00	1½	1½	2	--	- -	- -	- -	- -	- -	- -	- -	- -
0	3	3	5	--	- -	- -	- -	- -	- -	- -	- -	- -
1	7½	7½	10	7½	7½	10	10	10	15	10	10	15
2	10	15	25	10	15	25	20	25	40	20	25	40
3	25	30	50	25	30	50	40	50	75	40	50	75
4	40	50	100	40	50	100	75	75	150	60	75	150
5	75	100	200	75	100	200	150	150	350	150	150	300
6	150	200	400	150	200	400	- -	300	600	300	350	700
7	--	300	600	- -	300	600	- -	450	900	500	500	1000
8	--	450	900	- -	450	900	- -	700	1400	750	800	1500
9	- -	800	1600	- -	800	1600	- -	1300	2600	1500	1500	3000

STARTER ENCLOSURES

TYPE	NEMA ENCLOSURE
1	General Purpose – Indoor
2	Driproof—Indoor
3	Dusttight, Raintight, Sleettight –Outdoor
3R	Raintight, Sleet Resistant—Outdoor
3S	Dusttight, Raintight, Sleettight—Outdoor
4	Watertight, Dusttight, Sleet Resistant-Indoor & Outdoor
4X	Watertight, Dusttight, Corrosion-Resistant—Indoor & Outdoor
5	Dusttight, Drip-Proof--Indoor
6	Occasionally Submersible, Watertight, Sleet Resistant—Indoor & Outdoor
6P	Watertight, Sleet Resistant—Prolonged Submersion—Indoor & Outdoor
12	Dusttight and Driptight—Indoor
12K	Dusttight and Driptight, with Knockouts—Indoor
13	Oiltight and Dusttight—Indoor
	HAZARDOUS LOCATION STARTERS
7	Class I, Group A, B, C or D Hazardous Locations—Indoor
8	Class I, Group A, B, C or D Hazardous Location—Indoor & Outdoor
9	Class II, Group E, F or G Hazardous Locations—Indoor
10	Requirements of Mine Safety and Health Administration

CONVERSION OF NEMA TYPE NUMBERS
TO IEC CLASSIFICATION DESIGNATIONS

(Cannot be used to convert IEC Classification Designations to NEMA Type Numbers)

NEMA ENCLOSURE TYPE NUMBER	IEC ENCLOSURE CLASSIFICATION DESIGNATION
1	IP10
2	IP11
3	IP54
3R	IP14
3S	IP54
4 and 4X	IP56
5	IP52
6 and 6P	IP67
12 and 12K	IP52
13	IP54

Note: This comparison is based on tests specified in IEC Publication 529.
Reference: Information in the above tables is based on NEMA Standard 250-1991.

NEMA SIZE STARTERS
FOR SINGLE-PHASE MOTORS

SIZE OF CONTROLLER	CONTINUOUS CURRENT RATING (AMPERES)	HORSEPOWER	
		AT 115V	AT 230V
00	9	1/3	1
0	18	1	2
1	27	2	3
1P	36	3	5
2	45	3	7½
3	90	7½	15

Reference: NEMA ICS2-1993, Table 2-4-2.

DERATING FACTORS FOR
CONDUCTORS IN A CONDUIT

NUMBER OF CURRENT CARRYING CONDUCTORS	PERCENT OF VALUES IN TABLES AS ADJUSTED FOR TEMPERATURE IF NECESSARY
4-6	80
7-9	70
10-20	50
21-30	45
31-40	40
41 & Above	35

TEMPERATURE CLASSIFICATION OF INSULATION SYSTEMS

INSULATION SYSTEMS*		TEMPERATURE CLASSIFICATION	
Class A	Class 105	105°C	221°F
Class E**	Class 120	120°C	248°F
Class B	Class 130	130°C	266°F
Class F	Class 155	155°C	311°F
Class H	Class 180	180°C	356°F
Class N	Class 200	200°C	392°F

***IEEE Std. 117.**
****Used in European equipment.**

Insulation systems are arranged in order of their insulation level and classified by a letter symbol or by a numerical value.
The numerical value relates to the temperature classification of the insulation system.
The temperature classification indicates the maximum (hot-spot) temperature at which the insulation system can be operated for normal expected service life.
In general, all materials used in a given insulation system should be rated for temperatures equal to, or exceeding, the temperature classification of the system.

RESISTANCE TEMPERATURE DETECTORS (RTDs)

METAL	**CHARACTERISTIC**	**TRC (W/W/°C)***
COPPER	10.0W @ 25°C	.00427
PLATINUM	100W @ 0°C	.00385
NICKEL	120W @ 0°C	.00672

***TCR is the Temperature Coefficient of Resistance.**

THERMOCOUPLE JUNCTION TYPES

JUNCTION TYPE	**THERMOCOUPLE MATERIALS**
E	CHROMEL-CONSTANTAN
J	IRON-CONSTANTAN
K	CHROMEL-ALUMEL
T	COPPER-CONSTANTAN

DETERMINING THE POLARIZATION INDEX OF MACHINE WINDINGS

Knowing the polarization Index of a motor or generator can be useful in appraising the fitness of the machine for service. The index is calculated from measurements of the winding insulation resistance.

Before measuring the insulation resistance, remove all external connections to the machine and completely discharge the windings to the grounded machine frame.

Proceed by applying either 500 or 1000 volts dc between the winding and ground using a direct-indicating, power-driven megohmmeter. For machines rated 500 volts and over, the higher value is used. The voltage is applied for 10 minutes and kept constant for the duration of the test.

The polarization index is calculated as the ratio of the 10-minute to the 1-minute value of the insulation resistance, measured consecutively.

$$\text{Polarization Index} = \frac{\text{Resistance after 10 minutes}}{\text{Resistance after 1 minute}}$$

The recommended minimum value of polarization index for ac and dc motors and generators is 2.0. Machines having windings with a lower index are less likely to be suited for operation.

The polarization index is useful in evaluating windings for:
- **Buildup of dirt or moisture.**
- **Gradual deterioration of the insulation (by comparing results of tests made earlier on the same machine).**
- **Fitness for overpotential tests.**
- **Suitability for operation.**

The procedure for determining the polarization index is covered in detail by IEEE Standard No. 43.

CAUTION: Before proceeding with this test, the winding must be discharged against the frame.

USEFUL FORMULAS

FORMULAS FOR ELECTRICAL MOTORS

TO FIND	DIRECT CURRENT	SINGLE PHASE	THREE PHASE
HORSE-POWER	$\frac{E \times I \times EFF}{746}$	$\frac{E \times I \times EFF \times PF}{746}$	$\frac{1.732 \times E \times I \times EFF \times PF}{746}$
CURRENT	$\frac{746 \times HP}{E \times EFF}$	$\frac{746 \times HP}{E \times EFF \times PF}$	$\frac{746 \times HP}{1.732 \times E \times EFF \times PF}$
EFFICIENCY	$\frac{746 \times HP}{E \times I}$	$\frac{746 \times HP}{E \times I \times PF}$	$\frac{746 \times HP}{1.732 \times E \times I \times PF}$
POWER FACTOR	------	$\frac{\text{Input Watts}}{E \times I}$	$\frac{\text{Input Watts}}{1.732 \times E \times I}$

E = Volts **I = Amperes**
EFF = Efficiency (decimal) **PF = Power factor (decimal)**
HP = Horsepower

FORMULAS FOR ELECTRICAL CIRCUITS

TO FIND	DIRECT CURRENT	SINGLE PHASE	THREE PHASE
AMPERES	$\frac{\text{Watts}}{\text{Volts}}$	$\frac{\text{Watts}}{\text{Volts} \times \text{Power Factor}}$	$\frac{\text{Watts}}{1.732 \times \text{Volts} \times \text{Power Factor}}$
VOLT-AMPERES	– – – – –	Volts x Amperes	1.732 x Volts x Amperes
WATTS	Volts x Amperes	Volts x Amperes x Power Factor	1.732 x Volts x Amperes x Power Factor

OHMS LAW	CAPACITANCE IN MICROFARADS AT 60 HZ
Ohms = Volts/Amperes (R = E/I) Amperes = Volts/Ohms (I = E/R) Volts = Amperes x Ohms (E = IR)	Capacitance $= \frac{26500 \times \text{Amperes}}{\text{Volts}}$ Capacitance $= \frac{2.65 \times \text{kVAR}}{(\text{Volts})^2}$

USEFUL FORMULAS

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TEMPERATURE CORRECTION OF WINDING RESISTANCE

$$R_C = R_H \times \frac{(K + T_C)}{(K + T_H)}$$

$$R_H = R_C \times \frac{(K + T_H)}{(K + T_C)}$$

VALUE OF K	
Material	**K**
Aluminum	225
Copper	234.5

R_C = Resistance at temperature T_C (Ohms)

R_H – Resistance at temperature T_H (Ohms)

T_C = Temperature of cold winding (°C)

T_H = Temperature of hot winding (°C)

MOTOR APPLICATION FORMULAS
OUTPUT

$$\text{Horsepower} = \frac{\text{Torque (lb. ft) x RPM}}{5250}$$

$$\text{Kilowatts} = \frac{\text{Torque (N•m) x RPM}}{9550}$$

$$\text{Torque (lb.ft)} = \frac{\text{Horsepower x 5250}}{\text{RPM}}$$

$$\text{Torque (N•m)} = \frac{\text{Kilowatts x 9550}}{\text{RPM}}$$

SPEED – AC MACHINERY

$$\text{Synchronous RPM} = \frac{\text{120 x Frequency (Hz)}}{\text{Number of Poles}}$$

$$\text{Percent slip} = \frac{\text{Synchronous RPM = Full-load RPM}}{\text{Synchronous RPM}} \times 100$$

TIME FOR MOTOR TO REACH OPERATING SPEED (IN SECONDS)

$$\text{Seconds} = \frac{Wk^2\text{ (lb.ft.}^2\text{) x Speed Change (RPM)}}{\text{308 x Avg. Accelerating Torque (lb.ft.)}}$$

$$WK^2 = \text{Inertia of rotor} + \frac{\text{Inertia of Load x Load RPM}^2}{\text{Motor RPM}^2}$$

$$\text{Average accelerating torque} = \frac{[(FLT + BDT)/2] + BDT + LRT}{3}$$

Where: **BDT = Breakdown torque**
FLT = Full-load torque
LRT = Locked-rotor torque

MOTOR APPLICATION FORMULAS—CONTINUED
SHAFT STRESS

$$\text{Shaft stress (psi)} = \frac{HP \times 321.000}{RPM \times D^3}$$

$$\text{Shaft stress (kg/mm}^2\text{)} = \frac{KW \times 4.96 \times 10^6}{RPM \times D^3}$$

Where:

D = Shaft diameter (in or mm)
HP = Motor output
KW = Motor output
psi = Pounds per square inch
RPM = Revolutions per minute

CENTRIFUGAL APPLICATIONS
AFFINITY LAWS

$$\frac{Flow_1}{Flow_2} = \frac{RPM_1}{RPM_2}$$

$$\frac{Pres_1}{Pres_2} = \frac{(RPM_1)^2}{(RPM_2)^2}$$

$$\frac{HP_1}{HP_2} = \frac{(RPM_1)^3}{(RPM_2)^3}$$

Where:
Pres = Pressure
RPM = Revolutions per minute

FANS AND BLOWERS

$$HP = \frac{CFM \times PSF}{33000 \times \text{Efficiency of Fan}}$$

$$HP = \frac{CFM \times PIW}{6343 \times \text{Efficiency of Fan}}$$

$$HP = \frac{CFM \times PSI}{229 \times \text{Efficiency of Fan}}$$

Where:
CFM = Cubic feet per minute
PIW = Inches of water gauge
PSF = Pound per square foot
PSI = Pounds per square inch

PUMPS

$$HP = \frac{GPM \times FT \times \text{Specific Gravity}}{3960 \times \text{Efficiency of Pump}}$$

$$HP = \frac{GPM \times PSI \times \text{Specific Gravity}}{1713 \times \text{Efficiency of Pump}}$$

Where:
FT = Head in feet*
GPM = Gallons per minute
PSI = Pounds per square inch

*Head in feet = 2.31 x pounds per square inch gravity.

VOLUME OF LIQUID IN A TANK

Gallons = $5.875 \times D^2 \times H$

1 gallon (US) of water weighs 8.35 lb.

Specific gravity of water = 1.0

Where:
D = Tank diameter (ft)
H = Height of liquid (ft)

GLOSSARY

ALTERNATOR — A synchronous machine used to convert mechanical power into alternating current electric power.

AMBIENT TEMPERATURE — The temperature of the surrounding cooling medium. Commonly known as room temperature when the air is the cooling medium in contact with the equipment.

BASE LINE — A vibration reading taken when a machine is in good operating condition that is used as a reference for monitoring and analysis.

BREAKDOWN TORQUE — The maximum torque that an ac motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed. Also termed pull-out torque or maximum torque.

CODE LETTER — A letter which appears on the nameplates of ac motors to show their locked-rotor kilovolt-amperes per horsepower at rated voltage and frequency.

CONSTANT HORSEPOWER MOTOR — A term used to describe a multispeed motor in which the rated horsepower is the same for all operating speeds. When applied to a solid state drive unit, it refers to the ability to deliver constant horsepower over a predetermined speed range.

CONSTANT TORQUE MOTOR — A multispeed motor for which the rated horsepower varies in direct ratio to the synchronous speeds. The output torque is essentially the same at all speeds.

DELTA CONNECTION — A three-phase winding connection in which the phases are connected in series to form a closed circuit.

DESIGN — NEMA design letters A, B, C, D, and E define certain starting and running characteristics of polyphase squirrel cage induction motors. These characteristics include locked-rotor torque, locked-rotor current, pull-up torque, breakdown torque, slip at rated load, and the ability to withstand full-voltage starting.

DUTY — A continuous or short-time rating of a machine. Continuous-duty machines reach an equilibrium temperature within the temperature limits of the insulation system. Machines which do not, or can not, reach an equilibrium temperature have a short-time or intermittent-duty rating. Short-time ratings are usually one hour or less for motors.

EFFICIENCY — The ratio between useful work performed and the energy expended in producing it. It is the ratio of output power divided by the input power.

FOOT-POUND — The amount of work, in the English system, required to raise a one pound weight a distance of one foot.

FREQUENCY — The number of cycles in a time period (usually one second). Alternating current frequency is expressed in cycles per second, termed Hertz (Hz).

FULL-LOAD CURRENT — The current required for any electrical machine to produce its rated output or perform its rated function.

FULL-LOAD SPEED — The speed at which any rotating machine produces its rated output.

FULL-LOAD TORQUE — The torque required to produce rated power at full-load speed.

HARMONIC — A multiple of the fundamental electrical frequency. Harmonics are present whenever the electrical power waveforms (voltage and current) are not pure sine waves.

HERTZ (HZ) — The preferred terminology for cycles per second (frequency).

HORSEPOWER — A unit for measuring the power of motors or the rate of doing work. One horsepower equals 33,000 foot-pounds of work per minute (550 ft. lbs. per second) or 746 watts.

IEC — International Electrotechnical Commission.

IEEE — Institute of Electrical and Electronics Engineers.

INSULATION — Non-conducting materials separating the current-carrying parts of an electric machine from each other or from adjacent conducting material at a different potential.

INSULATION CLASS — A letter or number that designates the temperature rating of an insulation material or system with respect to thermal endurance.

KILOWATT — A unit of electrical power. Also, the output rating of motors manufactured and used off the North American continent.

LOCKED-ROTOR CURRENT — Steady-state current taken from the line with the rotor of a motor at standstill and at rated voltage and frequency.

LOCKED-ROTOR TORQUE — The minimum torque that a motor will develop at standstill for all angular positions of the rotor, with rated voltage applied at rated frequency.

MEGOHMMETER — An instrument for measuring insulation resistance.

MOTOR — A rotating machine that converts electrical power (either alternating current or direct current) into mechanical power.

NEC	*National Electrical Code.*
NEMA	National Electrical Manufacturers Association.
NEWTON-METER	Unit of torque, in the metric system, that is a force of one newton, applied at a radius of one meter and in a direction perpendicular to the radius arm.
PART-WINDING STARTING	A part-winding start polyphase motor is one arranged for starting by first energizing part of its primary winding and, subsequently, energizing the remainder of the primary winding. The leads are normally numbered 1, 2, 3 (starting) and 7, 8, 9 (remaining).
POLES	The magnetic poles set up inside an electric machine by the placement and connection of the windings.
POUND-FOOT	Unit of torque, in the English system, that is a force of one pound, applied at a radius of one foot, and in a direction perpendicular to the radius arm.
POWER FACTOR	The ratio of watts to volt-amperes of an ac electric circuit.
RATED TEMPERATURE RISE	The permissible rise in temperature above ambient for an electric machine operating under load.
RESISTANCE TEMPERATURE DETECTOR (RTD)	A device used for temperature sensing consisting of a wire coil or deposited film of pure metal for which the change in resistance is a known function of temperature. The most common type is nickel, with other types being copper, platinum, and nickel-iron.
ROTOR	The rotating element of any motor or generator.
SERVICE FACTOR	A multiplier which, when applied to rated power, indicates a permissible power loading that may be carried under the conditions specified for the service factor.
SLIP	The difference between synchronous and operating speeds, compared to synchronous speed, expressed as a percentage. Also the difference between synchronous and operating speeds, expressed in rpm.
STARTING TORQUE	The torque produced by a motor at rest when power is applied. For an ac machine, this is the locked-rotor torque.
STATOR	The stationary part of a rotating electric machine. Commonly used to describe the stationary part of an ac machine that contains the power windings.
SYNCHRONOUS SPEED	The speed of the rotating machine element of an ac motor that matches the speed of the rotating magnetic field created by the armature winding. $\text{Synchronous speed} = \frac{\text{(Frequency x 120)}}{\text{(Number of Poles)}}$
THERMISTOR	A resistive device used for temperature sensing that is composed of metal oxides formed into a bead and encapsulated in epoxy or glass. A typical thermistor has a positive temperature coefficient; that is, resistance increases dramatically and non-linearly with temperature. Though less common, there are negative temperature coefficient thermistors.
TORQUE	The rotating force produced by a motor. The units of torque may be expressed as pound-foot, pound-inch (English system), or newton-meter (metric system).
TRENDING	Analysis of the change in measured data over at least three data measurement intervals.
VARIABLE-TORQUE MOTOR	A multispeed motor in which the rated horsepower varies as the square of the synchronous speeds.
WYE CONNECTION	A three-phase winding connection formed by joining one end of each phase to make a "Y" point. The other ends of each phase are connected to the line. Also termed a star connection.
WYE-DELTA STARTING	Wye-delta is a connection which is used to reduce the inrush current and torque of a polyphase motor. A wye (star) start, delta run motor is one arranged for starting by connecting to the line with the winding initially connected wye (star). The winding is then reconnected to run in delta after a predetermined time. The lead numbers for a single run voltage are normally 1, 2, 3, 4, 5 and 6.